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THE GREAT ICE AGE

—IN—

PENNSYLVANIA.

BY

PROF. H. CARVILL LEWIS.

[*Abstract of a Lecture, delivered at the Franklin Institute, January* 5, 1883.]

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THE GREAT ICE AGE IN PENNSYLVANIA.

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When Agassiz, over forty years ago, after a prolonged study of the Swiss glaciers, announced the conclusion that large portions of the continents of North America and Europe were once covered by an immense glacier, thousands of miles in extent, and several thousand feet in thickness, geologists the world over were startled at what then seemed a most improbable hypothesis. To-day there is hardly a truth in geology more widely accepted or capable of more conclusive proof.

It is here proposed to inquire into the nature of the facts which have led to such a conclusion, and especially to examine those facts in Pennsylvania, recently discovered, which prove the great glacier to have come within sixty miles of our own city.

The great "Northern Drift," as it has long been called by geologists, is a scattered deposit of stones and clay, which, unlike our stratified gravels and clays at Philadelphia, is a confused mixture irregularly dumped over the ground, thick in some places and thin in others, and

apparently unstratified by water. Large boulders are scattered through and upon this deposit, and upon close examination many of these boulders may be seen to be scratched longitudinally. They are of all sizes and shapes, generally rounded, yet often sharp. This deposit, often called *till* or *hardpan*, is not confined to the valleys and lowlands, but may be found covering the whole northern portion of our country, mountains as well as valleys, in an almost continuous mantle. Upon sharp mountain summits, and upon steep slopes, it is represented by the boulders and scratched stones alone; but on the other hand it may be as finely developed upon a high mountain plateau as at the level of the sea. The till has as much depth, and has just as characteristic features on the Alleghany plateau in Potter county, Pennsylvania, for example, at an elevation of over 2,500 feet, as it has at New York City at the level of the sea.

[A photograph was here thrown upon the screen, giving a section of *till* at one of the State quarries at Bangor, Northampton county, Pennsylvania. Large boulders lay imbedded in it at all angles.]

The boulders scattered in great numbers throughout the region covered by the Northern Drift can always be shown to have been transported from a more northern region. The lecturer had found boulders of syenite from the Adirondack mountains, and of granite from Canada of frequent occurrence in Pennsylvania. These are often perched upon mountain summits, and often are lifted from one valley and carried across a mountain range to the south into another valley. Thus the lecturer had found, in the valley immediately south of the Kittatinny mountain, immense boulders of Helderberg fossiliferous limestone which had been derived from outcrops in a valley north of the mountain, the boulders having traveled across the intervening mountain range, 1,500 feet high.

[A photograph was shown of a boulder of conglomerate perched upon the summit of Penobscot Knob, 2,220 feet high, the boulder having been transported from the next mountain on the north and carried across an intervening valley.]

These boulders, as well as the smaller stones imbedded in the till, are frequently scratched as though by some sharp instrument. The scratches on the stones are generally lengthwise, and form a characteristic feature of true till. Nowhere outside of the region covered by the Northern Drift, *except in the vicinity of glaciers*, do similar scratched stones occur.

[Numerous specimens of scratched stones from various parts of the State were exhibited, and a photograph of a large scratched boulder was shown.]

On exposed surfaces of rock, or where the till has been removed by any means, the rocks may be observed to be scratched, grooved, or polished as though by the movement of some solid heavy mass across it.

These grooves or striations are almost always in a southerly direction, and always correspond with the direction in which the accompanying boulders had been transported. The rocks underlying the till are ground off; all decomposed material having been rubbed off and removed by the agent which made the striæ and transported the boulders. No exposures of decomposed rock, such as may be seen anywhere in the vicinity of Philadelphia (at Gray's Ferry, for example), occur in the region of the great Northern Drift. The smooth, rounded surfaces of rock in that region are sometimes known as "*roches moutonnées*," from their resemblance to the rounded backs of sheep.

[A photograph of striated rock surfaces on Godfrey's ridge, near the Delaware Water Gap, were thrown upon the screen, and specimens exhibited.]

These three phenomena, then, the mantle of till, the transported and scratched boulders, and the smoothed or striated rock surfaces, are characteristic of the region covered by the "Northern Drift," and, with the high-level gravel banks and other phenomena more particularly to be described hereafter, are common throughout large portions of northwestern Europe and northeastern America. It was to satisfactorily explain these phenomenon that Agassiz's theory was proposed.

The early geologists supposed that this great Northern Drift was caused by an immense flood or deluge, the great mass of which swept furiously from the north toward the south, engulfing mountains and valleys alike, and carrying with it great masses of stones and rubbish, which, after the subsidence of the flood, remained as the deposits just described. It was found, however, that no satisfactory cause for such a flood or for such waves of translation could be found; nor could it be shown that water, however heavily laden with detritus, could either scratch the stones it bore, striate and groove rock surfaces, or form unstratified *till*. Nor could any flood transport great boulders across successive mountain ranges to positions often higher than the parent rock.

Another theory was therefore proposed. Great icebergs were supposed to have floated upon an inland sea, and to have both carried the boulders, and to have striated any rocks on which they might have grounded. On the other hand, the absence of any evidences of water

action throughout large regions covered by the till, the absence of any proof that icebergs can produce striæ, the difficulty of explaining the transportation of boulders from valleys to mountain tops, and especially the entire absence of any shore line for such an inland sea, militate strongly against any such theory. The southern edge of the "Northern Drift" beginning at the Atlantic ocean, and extending westward across the Alleghanies in a diagonal line, is anything but a shore line. This theory, however, known as the Iceberg Theory, is still supported by a few geologists, and will therefore be again referred to in our description of the glacial phenomena of Pennsylvania.

The glacial theory of Agassiz, on the other hand, somewhat modified by more recent discoveries, explains the observed facts and is based upon observations of phenomena produced at the present time. At the foot of many of the Swiss glaciers which have retreated from a former position, there may be seen polished and striated rock surfaces, transported and scratched boulders, drift deposits, and many other appearances precisely similar to those exhibited on a larger scale in northern Europe and America.

[The lecturer here described a personal examination of the termini of several Swiss glaciers, and especially of a valley between Meyringen and the Grimsel, where the polished rocks high up on either side showed the valley to be the deserted bed of a glacier.]

There are numerous proofs that the glaciers of Switzerland were formerly of enormously greater size than at present. There are boulders lying on the eastern flank of the Jura mountains which have been carried from Mt. Blanc upon the bosom of a great glacier 150 miles long, 50 miles broad, and 2,000 feet deep. An equally large stream of ice flowed southward from the same mountain far into Italy. A colder climate must have once prevailed to produce such a great extension of the glaciers.

In America also, both in the Rocky Mountains, and in the Sierra Nevada, there were formerly extensive glaciers, where now none, or only traces remain.*

Coming now to the great glacier of central Greenland, which with its extension northward to the Pole makes a true Polar ice-cap, it is most reasonable to suppose that the same refrigeration of climate which caused the local glaciers of Switzerland and of the Rocky and

* Similar evidences of the former greater extension of glaciers are found in many portions of the globe.

Sierra mountains to expand, caused similar great expansion of the Polar ice-cap.

A sea of ice, more than one thousand miles long, and thousands of feet in thickness, never traversed by human feet, now covers the whole interior of Greenland, mountains and valleys alike being buried beneath its mass.

[A description of this great *mer de glace*, as seen by Hayes, Nordenskjöld, and others, was here given.]

Streams of ice, issuing from this Greenland glacier often push far out to sea, where, by the buoyancy of the water, great icebergs are detached. These icebergs are often as much as half a mile in thickness, getting aground in water of that depth.

A sea of ice of even greater thickness covers the Antarctic continent, forming at its edge a wall of ice so high that one could not see over it from the top of a ship's masthead. Croll has estimated the thickness of the Antarctic glacier at its centre to be at least *twelve miles*.

Imagine now, these great polar ice-caps expanded in equal proportion with the local glaciers elsewhere, and the glacial theory is before us.

There is every proof that, ages ago, the climate being colder than now, the great Greenland glacier crept down so as to overspread the northeastern part of America and the northwestern part of Europe. Receiving accessions from such local centres of glaciation as Scandinavia, Scotland, and possibly Labrador, it probably also filled the bed of the Atlantic with ice far south of Greenland, the edge of the glacier reaching from Newfoundland to southern Ireland in a concave line. In its southward advance this great glacier scratched off rock surfaces, striated them in the direction of its motion, and scratched the fragments held in its grasp. Just as the ancient Swiss glacier carried boulders from Mont Blanc to the Juras, so this great continental glacier carried them from Canada across Lake Erie into Pennsylvania. Just as the Greenland glacier now fills the valleys and overtops the mountains, so this larger glacier advanced over mountain and valley alike, in a continuous sheet, to its final halting place, only sixty miles north of Philadelphia.

It is probable that future research will show a similar great ice-sheet to have advanced northward from the Antarctic continent.

This great northern glacier, reaching in America from Greenland to St. Louis, and from Alaska to New Jersey, was so thick as to overtop

Mt. Washington, dropping transported boulders upon its summit. Even at its very edge, as observed in Pennsylvania, the glacier was at least 800 feet thick. A hundred miles back from its edge, among the Catskills, it was at least 3,100 feet thick, while two hundred miles farther, in northern New England it was 5,000 feet thick. In northern Canada it must have been still thicker.

The thickness of the glacier is known by the height to which transported boulders and striated rock surfaces may be found. Thus in Pennsylvania, the lecturer has found that Pocono Knob, 2,175 feet high, juts into the extreme edge of the glacier, having however no marks of glaciation, and therefore showing the edge of the ice not to have been deep enough to ride over it, while, on the other hand, Penobscot Knob, 2,250 feet high, only eight miles back from the southern edge of the glacier, was overridden by it, exhibiting striations and transported boulders upon its very summit.

It was this glacier which formed the till, which dumped down irregularly the various unstratified deposits so characteristic of the drift-curved region, and which both abraded the rock surfaces and transported and rounded the fragments which it tore off in its passage.

The exact extent of this great glacier is not accurately known in all portions, but is now being studied. In general, it appears that its southern edge extended from Alaska in a southwest direction to the northwest corner of Dakota, whence it passed through the centre of Nebraska and the northeastern corner of Kansas, continuing eastward through the centre of Missouri to the Mississippi river near St. Louis. It then passed along the southern edges of Illinois and Indiana, entering Ohio at Cincinnati, then trending northwest to the Pennsylvania line a few miles north of Beaver. In Pennsylvania, as will presently be stated more in detail, it passed northwest from Beaver county to Warren county, where it entered New York. Making a sharp curve in Cattaraugus county, New York, it again entered Pennsylvania in Potter county, and passed southeast to Belvidere in Northampton county, where it crossed into New Jersey. Passing in a southeast direction across New Jersey to Staten Island, it again entered New York, and traversing the whole length of Long Island finally goes out to sea, appearing on Block Island, Cape Cod, and at a few other detached points. The edge of the glacier probably corresponded with St. George's bank and Sable Island shoal outside of Nova Scotia, and, passing southeast of Newfoundland and south of Greenland,

probably crossed the Northern Atlantic and again passed southward outside of the Irish coast, so as to enter the southwest corner of England. It appears to have crossed England in a westerly direction so as to pass not far from London, and then, crossing the North Sea, to have traversed southern Holland, northern Austria, Saxony, passing near Dresden, until entering Poland, south of Warsaw, it finally curved northeast in Russia, passing east of Moscow, and entering the Arctic Ocean just west of the Ural mountains.

[A map of the world was exhibited, showing the approximate limit of glaciation.]

The glacial stream was reinforced by glaciers from the mountains of Scotland and Scandinavia, and these local glaciers have been proved to have remained and to have formed striæ long after the continuous ice-sheet had departed. There are many evidences of a second glaciation of more limited size and of local origin.

That the phenomena of this great drift-covered region are due to the actual presence of a great glacier, rather than to any open sea, bearing icebergs, should be forever settled by the discovery of one crucial fact, the presence of a *terminal moraine*. A true glacier pushes up at its foot a mound of unstratified material, composed of angular, rounded, and striated fragments of rock, which the ice has taken up at various points along its course and carried to its terminus to form a moraine. On the other hand any body of water is bounded by a level shore line composed in great part of water-worn pebbles.

By the discovery in Pennsylvania and in other portions of America of a true terminal moraine, which, as a continuous wall of unstratified and glaciated material, crosses over mountain and valley alike, regardless of topography, everywhere forming the boundary between the glaciated and the non-glaciated region, the glacial theory has recently been remarkably confirmed.

[Professor Lewis here described the investigations in New Jersey, and along Long Island and southern Massachusetts, which first demonstrated the existence of a true terminal moraine, and referred to the discovery of similar moraines in Wisconsin and Minnesota, which marked halting places in the retreat of the glacier. He stated that the "coteaus" of the northwestern prairies have been shown to be parts of such moraines.]

Convinced from personal observations as well as from the considerations just mentioned, that it was possible to trace a terminal moraine across Pennsylvania, the lecturer, having obtained the aid of the Geological Survey of Pennsylvania, and having, through part of the

exploration, the able assistance of Prof. G. F. Wright, had been able to follow and define the southern limit of glaciation for the first time in a continuous line four hundred miles in length across our State, and to find that it is everywhere marked by a remarkable accumulation of glaciated material, which, forming a great terminal moraine, winds across mountains and valleys, across deep ravines and high mountain ridges, from the lowlands of the Delaware to the great Alleghany plateau, is continuous from end to end, and forms a feature of great interest in studies upon the glaciation of this country.

The method employed in discovering the line of the moraine was to zigzag along its course from the glaciated into the non-glaciated region, and *vice versa*, going each time far enough on the one side to be fully satisfied of the absence of glaciation, and on the other to find undoubted traces of its action.

The distinction between the glaciated portion of Pennsylvania and that region south of glacial action is very marked. Although the general topography of the two regions is alike, the varied superficial features due to glacial agencies, the far traveled and scratched boulders, the smoothed and striated rock exposures, the unstratified deposit of impure clay, which, filled irregularly with both round and sharp stones, has been called *till*, the long *hummocky* ridges of stratified sand and gravel known as *Kames*, and especially the numerous glacier-scratched fragments and pebbles, all these deposits are in strong contrast with those south of the glacial action, where all the gravels are stratified and the pebbles water-worn, where the rocks are never polished or striated, but, on the other hand, often decomposed to a great depth and where, except near the sea coast, wide stretches of the more elevated regions are perfectly free from all drift.

The line separating the glaciated from the non-glaciated region is especially defined by a remarkable accumulation of unstratified drift material and boulders, which, heaped up into irregular hills and hollows over a strip of ground nearly a mile in width, forms a continuous line of drift hills more or less marked, extending completely across the State. These hills vary in height from a few feet up to 100 to 200 feet, and while in some places marked merely by an unusual collection of large transported boulders, at other places rise as immense accumulations to form a noteworthy feature of the landscape. When typically developed, this accumulation is characterized by peculiar contours of its own. A series of *hummocks* or low conical hills, alternate

with short straight ridges, and enclose shallow basin-shaped depressions, which like inverted *hummocks* in shape, are known as *kettle holes*. Large boulders are scattered over the surface, and the unstratified *till* which composes the deposit is filled with glacier scratched boulders and fragments of all sizes and shapes. The average width of the moraine is about one mile.

The two facts which are of especial importance in relation to this line of drift hills are, (1.) That, as shown by the absence of stratification, by the angularity and the striated surfaces of its enclosed stones, and by its topograpical position, it has rarely been subjected to the action of water; (2.) That, as proved by numerous glacial striæ and by transported boulders, its course is always at right angles to the direction of glacial movement.

These facts, with others about to be given in detail, led the speaker to regard this accumulation as a true *terminal moraine*, marking the southern extension of the great ice-sheet of northeastern America. Like the moraine at the foot of the Rhone glacier, which, as recently observed by Chamberlin, forms diminutive hummocks and kettle holes, and has on a small scale the same characters and topography as the great moraines of Wisconsin, this great Pennsylvania moraine appears to have been pushed out at the foot of the great glacier of the ice age.

The general course of this moraine across our State is as follows (see accompanying map): Appearing first in Northampton county, a mile below Belvidere, at latitude 40° 49′, it appears through the stratified drift as low gravel hills, which, winding up over the slate hills to the west, are soon developed into an accumulation of typical till, holding kettle holes and filled with boulders. Winding in a great curve first westward and then northward, it reaches the base of the Kittatinny mountain three miles east of the Wind Gap.

Ascending to the top of the Kittatinny mountain, 1600 feet high, the moraine crosses over it, being well shown upon the very summit, and entering Monroe county, crosses the great valley between the Kittatinny and the Pocono, enclosing in its course several moraine lakes. Having crossed this valley, and reached the base of the Pocono escarpment, it swings sharply back and around Pocono Knob, immediately afterwards to ascend the steep face of the mountain to the wide platean on top, 2100 feet above the sea. Crossing this in a majestic curve, heaped up in an immense accumulation, it goes first north and afterwards west, until it reaches the Carbon county line.

Crossing the centre of Kidder township, Carbon county, it reaches the gorge of the Lehigh river, some ten miles north of Mauch Chunk. It crosses the gorge at Hickory run, and, without swerving from its general northwestern course, ascends mountain range after mountain range in Luzerne county, descends to the valley of the east branch of the Susquehanna, and crosses the river at Beach Haven, here forming immense heaps of drift, afterwards to be washed down the river into terraces.

Then, in Columbia county, following along the base of Huntington or Knob mountain for awhile, it finally ascends it, and crossing over the summit at a height of 1500 feet above the Susquehanna just below, descends the north slope of the mountain to the broad undulating valley to the north. Taking a northerly course, it follows up on the east bank of Fishing creek to the north or Alleghany mountain. The summit of the Alleghanies in Sullivan county is covered with glacial striæ, and contains boulders and other marks of glaciation. The moraine entering Lycoming county, passes westward along the base of the mountain, crossing in its course the Muncy and Loyalsock creeks, and finally, near the village of Loyalsock, turns at right angles and ascends the mountain.

Having reached the summit of the Alleghenies, over 2000 feet above the sea, it crosses the picturesque canon of Lycoming creek, and passing west through a wild, wooded region nearly as far as Pine creek, it begins a nearly straight northwestward course, through the southwest corner of Tioga county, and the northwest part of Potter. In the high ground of Potter county, the moraine crosses a great continental watershed, from which the waters flow into the Gulf of Mexico, Lake Ontario, and Chesapeake bay. The moraine is here finely shown at an elevation of 2580 feet, being higher than elsewhere in the United States.

The line of the moraine now enters the State of New York, in the southwest corner of Allegheny county. Passing still northwest and entering Cattaraugus county, it twice crosses the winding course of the Allegheny river, east and west of Olean, then, trending to a point five miles north of Salamanca, in latitude 42° 15′, it forms a remarkable apex, from whence to the Ohio line its course is southwest. Turning at right angles to its former course, the moraine passes southwest through the southeast corner of Chautauqua county, and keeping approximately parallel to the course of the Allegheny river, re-enters

Pennsylvania, in Pine Grove township, Warren county. It crosses the Conewango river seven miles north of Warren, forming immense accumulations in the valley of the river.

Then trending west in Warren county, still at a general elevation of nearly 2000 feet above the sea, it crosses one gorge after another, and forms a line separating, not only the glaciated from the non-glaciated region, but also the cultivated from the uncultivated and densely wooded region.

In Crawford county, the line appears in the southeast corner, and crosses Oil creek between four and five miles northwest of Titusville.

In Venango county it skirts the northwest and west boundary of the county, crossing French creek four miles west of Franklin.

It crosses the three northwest townships of Butler county, and the southeast corner of Lawrence. The Beaver river is crossed by the moraine eight miles south of New Castle.

The moraine traverses the extreme northwest corner of Beaver county, and, in the middle of Darlington township, thirteen miles north of the Ohio river, and at a latitude of 40° 50′, crosses the Ohio State line.

The moraine thus leaves Pennsylvania at precisely the latitude at which it entered the State, and if a straight line were drawn across the State between these two points, the line of the moraine would form with it a right angled triangle, whose apex was 100 miles distant perpendicularly from its base. The total length of the moraine, as here shown, is about 400 miles. The moraine crosses the Delaware at an elevation of 250 feet, the Allegheny at an elevation of 1425 feet, and the Beaver at an elevation of 800 feet above the sea, or 225 feet above Lake Erie. Upon the high lands it rises higher by 1000 feet or more.

Coming now to the details of the moraine, it will be impossible in the brief space of a lecture to mention more than a very few of the many interesting phenomena noticed all along its course. The details in full will be found in forthcoming Report Z. of the Geological Survey of the State. The beautiful photographs thrown upon the screen were made by Mr. E. H. Harden, of the Geological Survey, and are the first ever taken or exhibited of the Great Terminal Moraine in any part of the world.

[Photographs were exhibited of the moraine, near Bangor, Northampton county; details of the same; moraine near Saylorsburg, Monroe county; "kettle-holes" in the same; moraine on summit of Pocono mountain; moraine forming dam on Fishing creek, Columbia county, etc.]

In *Northampton* county, the moraine is very finely developed west of Bangor, where it forms a series of "hummocky" hills, which, 100 to 200 feet in height, and covered with transported and striated boulders, rise abruptly out of a clayey plain to the west. Glacial striæ upon exposed surfaces near Bangor point southwest, or towards the moraine. After following the moraine to the base of the Kittatinny mountain, it became of great interest to know whether a great lobe of ice descended from New Jersey along the lower side of the mountain, or whether a tongue projected through the Delaware Water Gap, or whether the glacier even so close to its southern limit, came bodily over the top of the mountain, unchecked by it, and unchanged in its course. The last, the most improbable of these hypotheses, and certainly the least expected by the speaker, proved to be undoubtedly the true one. The speaker had been able to show that the moraine crossed mountain near Offset Knob, that large boulders, derived from lower elevations several miles northward, lie perched all along the summit, 1400 feet above the sea, and that, as shown by the numerous striæ on the northern slope of the mountain, running *up-hill*, the glacier moved diagonally up and across the mountain, uninfluenced in any way by the presence of the Water Gap, and finally came to an end in the valley south of the mountain, as marked out by the terminal moraine. Huge boulders of fossiliferous limestone, sometimes 30 feet long, were torn by the ice from their parent strata in Monroe county, on the north side of the mountain, lifted up a thousand feet, carried across the mountain, and dropped finally in the slate valley of Northampton county. The lecturer had found one of these limestone boulders upon the very summit of the mountain, where the jagged sandstone rocks had combed it out of the ice during its passage across. The journeys of these boulders were short, but that of a well-rounded boulder of Adirondack syenite, which the lecturer had found in the same county, was about 200 miles.

In *Monroe* county, the course of the moraine as it winds from the top of the Kittatinny mountain down to Cherry Valley and then up again on to the Pocono, is a complete vindication of the glacial hypothesis. It is in no sense a water level, nor could it have been formed by floating ice. No other cause than that of a great glacier could form a continuous accumulation of glaciated material, which contains no evidences of water action and which follows such a course. The fact discovered that no tongues of ice were protruded either through the

Delaware Water Gap or down the broad valley between the Pocono and Kittatinny mountains, indicates the immense size of the glacier. Although more than 1000 feet lower than the mountains and 12 miles in width, the valley last mentioned deflected the southern boundary of the ice but a few miles.

[There are no striæ indicating passage of ice through the Water Gap, the supposed striæ being due to water action.]

Again, neither on the mountains nor in the valley does the moraine rest against any defined barrier as would be the case were it a shore-line.

The moraine is wonderfully shown upon the summit of Pocono mountain, over 2000 feet above the sea, where a great ridge of moraine hills twelve miles long, one mile wide, and 100 feet or more high, composed of unstratified till, and bearing numerous boulders of Adirondack gneisses and granites, rises out of the level, sandy plain of the Pocono plateau and sweeps around from Pocono Knob into Carbon county. Known locally as "Long Ridge," its origin has never before been suspected. It encloses remarkable little "moraine lakes" without inlet or outlet, and is heaped up into just such conical hills as may be seen in the moraine in Southern Massachusetts. Nothing can more clearly show the continuity and uniformity of action of the great glacier than the identity of its moraine accumulations at such remote points.

[The lecturer here described some of the *striæ* of Monroe county, exhibiting photographs. One photograph represents *cross striæ* seen south of Stroudsburg. A second movement of the glacier down hill, after it had become smaller, had crossed the striæ made by a more general movement of the ice. He said that the direction of ice movement could often be told from the cuneiform shape of the striæ.]

The "*Kames*" of Cherry Valley, fine examples of which appear south of Stroudsburg, are interesting relics of sub-glacial water action. They are composed of stratified water-worn gravel, having often an anticlinal structure, and, as a series of conical hills and reticulated ridges, enclosing "kettle holes," form conspicuous objects in the centre of the valley. They appear to have been formed by sub-glacial rivers, which flowing from the moraine *backwards*, under or at the edge of the ice, emptied into the Delaware Valley. A study of the great sub-glacial drainage, of which kames are the most prominent relics, throws much light upon certain high-level stratified gravels whose origin has been ascribed to great changes of elevation.

[Photographs of *Kames* in Cherry Valley were exhibited. The lecturer then described the *terraces* near Stroudsburg, and referred to the Indian name of that region, Minisink, meaning "the waters have gone," as an indication of the legendary memory of the flood following the retreat of the glacier. He exhibited a photograph of a glacial groove which he had discovered on the Kittatinny mountain near the Water Gap, which, six feet wide and seventy feet long, had been gouged out by some great rock imbedded in the moving glacier.]

Immense as was the power of the slowly moving glacier, it had but slight effect upon the topography of the country. It is a mistake to suppose that glaciers can level down mountains or scoop out cañons. The glacier has merely "sandpapered" the surface of the rocks. The glacier passed bodily across the sharp edge of the Kittatiny mountain without having any appreciable effect upon it, the glaciated part of the ridge being as high and as sharp as that part south of the moraine.

In *Carbon* county, the moraine passes across the wild wooded region in the most northern township of the county, enclosing several moraine lakes in its course and crossing the Lehigh near Hickory run. These moraine lakes are kettle-holes holding water, while other lakes, such as Long Pond on the Pocono plateau, are due to the damming up of their outlets by the moraine. An abundance of lakes is characteristic of a glaciated region, being generally due to the obstruction of streams by the unequal distribution of the till.

The point where the moraine crosses the Lehigh may be distinctly seen by any one traveling upon either the Lehigh Valley Railroad or the Lehigh and Susquehanna Railroad, the contrast between the glaciated and the non-glaciated regions being sharply defined. South of the moraine, the rocks bordering the picturesque gorge of the Lehigh are bare or covered with frost-broken fragments, while the products of aerial erosion known as "Pulpit Rocks" may be seen. The gorges formed by tributary streams are rocky and free from gravel. On the other hand, in the glaciated portion of the valley, a covering of gravel and rounded boulders appears on either side, and the drift has filled up the gorges occupied by tributary streams, often transforming them into shallow valleys, while terraces and ridges of gravel appear in the river valley itself. Just above White Haven, glacial striæ upon the rocks may be seen from the car windows.

The general movement of the ice throughout this region, as shown by the striæ upon the summit of Penobscot Knob, 2200 feet high, is south 10° west. This is precisely at right angles to the course of the

moraine. The latter traverses the southern part of *Luzerne* county in a direction north of west, crossing in its course numerous mountain chains, by each of which it is locally deflected northward.

[The lecturer here described some of the glacial phenomena of Luzerne county. He stated that at the point where the terminal moraine crosses Buck mountain, in a line diagonally across the mountain, the moraine is so sharply defined that he was able to stand with one foot upon the glaciated and the other upon the non-glaciated region. He described the fine kames between Scranton and Pittston, on the Lackawanna river, and showed that they were nearly parallel to the glacial striæ.

He then gave some details of the course of the moraine as traced through *Columbia* county. He stated that it was interesting to find that in *front* of a mountain chain; such as Huntington mountain or the Alleghany mountain, the moraine was poorly developed, as though the mountain had *combed out* the drift from the ice. Speaking of certain gravel deposits south of the moraine, due to floating ice, he said that the best test of a glaciated region is the striation of its pebbles.

He described an instructive portion of the moraine, where, 3½ miles northwest of Berwick, it seems to abut against a high slate hill, which furnishes, therefore, a *section* of the end of the glacier. It shows that the extreme edge of the ice was about 400 feet thick, and that while the moraine and the scratched pebbles were carried along at the base of the ice, sharp fragments of sandstone were carried on top.

The interesting course of the moraine along the eastern bank of Fishing creek was described, where the glacier stopped abruptly on the downward slope of a hill, stopping simply because its inertia became exhausted. A photograph of the moraine where it crossed the creek, forming a great dam, was exhibited, and it was shown that the moraine was often steeper at the back than at its front edge—a fact analogous with the features of modern Swiss moraines.

The evidences of glaciation upon the Alleghany mountain in Sullivan county were given, the striæ pointing south 9° west, and the moraine was followed along the base of the mountain to a point in *Lycoming* county near Loyalsock, where it climbed up to the great Alleghany plateau, and then, keeping at a high elevation, passed through Tioga and Potter counties into New York.]

That this great region of high elevation (over 2500 feet) had a decided influence upon the general course of the moraine is inferred from the local influence already shown by the lecturer to have been exerted by single mountain chains, and it is probable that as the lowlands along the Atlantic allowed the ice to flow as far south as Belvidere, so this great mountain region, acting like a wedge, caused the moraine to swing northward into New York; and so, too, the depressions of Lake Erie and the Mississippi Valley produced another and more

extended southward flow, a portion of which traversed the western part of our State.

[Professor Lewis here described the remarkable apex made by the moraine north of Salamanca, N. Y. He showed that it was probable that the Allegheny river flowed under a tongue of the glacier, 10 miles broad and 2 miles long, through a sub-glacial channel at the time of its greatest extension near Olean. He described a great natural dam across the valley of Great Valley creek, near Peth, where the moraine stretches across the valley from side to side, and he spoke of the contrast between the numerous drainage valleys which drained the waters of the melting ice into the Alleghany river, and those valleys which took their rise south of the moraine and were free from all drift.

After giving some details of the western lobe of the ice sheet in Pennsylvania, he spoke of some curious deposits of glaciated material which occurred in a narrow strip of ground immediately in front of the moraine, and which he had named the *fringe*. These deposits consisted of boulders of Canadian granite, and other rocks, which he found perched upon the summits of hills, sometimes as far as five miles in front of the moraine, though never farther. This glacial "fringe," confined to the western part of the State, was found to increase in width from two miles in Warren county, to five miles on the Ohio line, and was at first a puzzling phenomenon. The hypothesis proposed was that, like breakers on the seashore, the top of the ice overreached the lowest strata by the width of the "fringe," and that while the moraine marked the halting place of the bottom of the ice, by which it was formed, the far-transported boulders were carried on more rapidly in the top strata of the ice, and were dropped outside of the moraine to form the "fringe." Other facts observed in the western part of the State were given, and specimens of Canadian boulders were exhibited. It was stated that the striæ in the western part of the State all pointed southeast, being at right angles to those in the eastern part of the State, but like them, pointing always towards the moraine.]

Having thus reviewed briefly some of the more important glacial phenomena of our State, it remains to inquire into the probable *cause* of the great glacier, into the origin of the cold that allowed the polar ice-cap to creep down as far as the great terminal moraine, and finally into the probable *age* of the glacial epoch.

Among the various causes assigned, by different writers, for the glacial epoch, the following may be enumerated:

1. Changes in the obliquity of the ecliptic.
2. Changes in the position of the earth's axis of rotation.
3. The precession of the equinoxes, combined with a greater eccentricity of the earth's orbit.
4. Variations in the amount of heat given off by the sun.
5. Differences in the temperature of portions of space passed through by the earth.

6. Differences in the distribution of land and water, and differences in the elevation of certain portions of the earth.

7. Differences in the flow of oceanic currents, and a change of direction of the gulf stream.

8. Changes in the earth's atmosphere, in its capacity for allowing the radiation of heat, in its power of absorbing moisture, in its density and height, in its temperature, and in the height to which clouds can rise in polar regions.

Still other causes, such as the gradual cooling of the earth from a state of incandescence, have been assigned.

The most probable of these theories are the third and sixth of the above list.

[Professor Lewis here explained the astronomical changes which would cause the winters to be longer than the summers, thus preventing the melting of the accumulating snow. He showed that owing to the elliptical form of the earth's orbit we are about 3,000,000 miles nearer the sun in the winter than in the summer of the northern hemisphere, but that 10,500 years ago this condition of things was reversed, and that we were nearer the sun in summer. He showed also that whereas the sun is now nearly in the centre of the earth's orbit, about 100,000 years ago the eccentricity of our orbit was much greater, the pole then being 8,000,000 miles nearer the sun in winter than in summer. He thought, however, that terrestrial causes were much more potent in causing the glacial epoch than any astronomical changes. There is reason for believing that in glacial times, the land in Labrador and Greenland was elevated at least 600 feet higher than at present, and that at the same time the warm oceanic currents were withdrawn. The glacier grew in the neighborhood of the Atlantic and Hudson's Bay, where moisture was abundant, and did not reach into the dry interiors of either America or Asia. He explained Croll's molecular theory of the motion of the ice, and suggested the possibility of a glacier flowing towards an origin of heat without the aid of gravity.]

Finally, it becomes of interest to inquire into the length of the glacial epoch, and to estimate, if possible, the time that has elapsed since the glacier retreated from Pennsylvania to its present home in Greenland. Astronomical data teach that the cold period began 240,000 years ago. Now, just as every year the greatest cold of our winter does not occur at the time of the shortest day, but fully six weeks later, so it is evident that the greatest cold of the glacial epoch did not occur till many thousands of years after the date mentioned. Again, the great eccentricity of our orbit ended 80,000 years ago, but just as our winter snows remain long into the spring, so the great glacier remained long after its immediate cause had been withdrawn. The larger the mass of ice, the longer it would take to melt. There are

data which lead us to believe that the glacier did not finally withdraw from the United States until as recently as 10,000 to 15,000 years ago. We are here on delicate ground, for geological time is relative rather than absolute, and it is not safe to fix dates. Even in history, all dates back of the time of Abraham are most uncertain.

Special interest, however, attaches to speculations regarding the time of the close of the glacial epoch, since it has been shown to be closely connected with the antiquity of the human race. Stone implements, made by man, have been discovered on both continents in gravels deposited at the close of the glacial epoch. They have been found under conditions that leave no doubt that man, in a rude state, with habits resembling those of the Esquimaux, lived at the time when the river valleys were flooded with water from the melting glacier. That man existed before the glacial epoch, has been inferred from certain facts, but not satisfactorily proven. The speaker has made careful search in glacial deposits all along the line of the moraine for traces of man, without success; while, on the other hand, in the post-glacial gravels of the Delaware, as will be shown in the next lecture, human implements have been found in abundance by Dr. Abbott.

So important, therefore, does the time of the final melting of the glacier become, that we are tempted to inquire still further, even at the risk of too greatly prolonging this lecture, and to gather what facts we can to bear on our subject.

It is a question which geological data alone are insufficient to solve. The only clew, and that a most unsatisfactory one, is afforded by calculations based upon the amount of erosion. This, like all geological considerations, is relative rather than absolute, yet several calculations have been made, which, based either upon the rate of erosion of river channels, or the rate of accumulation of sediment, have attempted to fix the date of the close of the glacial epoch.

When a student of surface geology, who has lived south of glacial action, examines for the first time the true glacial drift and sees the kame-like ridges and bowl-shaped depressions maintaining regular outlines and steep slopes, he cannot but be struck with the comparatively recent look of these deposits. He cannot but believe that if the great periods of time have elapsed since their depositions, which some geologists maintain, the gravel ridges would be rounded down and the kettle-holes filled up by the erosive action of frost, rain and wind. Recent investigations in glacial geology are bringing forward many

evidences that the final disappearance of the glacier in eastern America was not far remote.

Prof. Chamberlin's statement, that "no sensible denudation has taken place in Wisconsin since the glacial times in either drift bearing or driftless areas;" Mr. Upham's remark, when speaking of the lakes which dot the surface of Minnesota, that "the lapse of time since the ice age has been insufficient for rains and streams to fill these basins with sediment, or to cut outlets low enough to drain them; though in many instances we can see such changes slowly going forward;" and Dr. Dawson's observation that "In Canada, the character of the river-courses cut through the glacial beds, and their very unformed and imperfect excavation would lead to the belief that only a few thousands of years have elapsed since the glacial beds were laid down;" these, with similar observations by the lecturer, all agree with conclusions drawn from the good preservation of shells and bones in terrace deposits, and the fact that in zoology since the glacial age no geological changes even leading to the production of varieties have occurred, in bringing the close of the glacial age into our own epoch.

Prof. Wright finds from a study of a glacial "kettle hole" in Massachusetts, that the accumulation of peaty matter in it, whether caused by growth of vegetation or by winds and rains, is equal to a level deposit of eight feet in thickness. At the rate of one inch in a century, which is probably less than the true rate, this would place the close of the glacial epoch at less than ten thousand years ago.

A still more recent estimate has been made by Dr. Andrews, who, from calculations based upon the erosive action of the great lakes, concludes that the total lake deposits made since the glacial epoch, were formed within seventy-five hundred years.

Another source of calculation is the recession of the falls of a river since glacial times. The most notable calculation of this kind is that made upon the recession of the Falls of Niagara. A gorge seven miles in length has been cut from Lewiston to the present falls. Beds containing recent shells and mastodon teeth occur in the banks above the gorge, at the whirlpool, three miles below the falls, and also on Goat Island above the falls, indicating that the waters of Lake Erie once extended up over the gorge and present falls, and that since that period a large portion of the gorge had been excavated. At the whirlpool is an ancient pre-glacial channel, which, having been filled

with drift in glacial times, forced the river to cut a new channel through the rock since that period.

There are here, therefore, data for calculating the close of the glacial epoch. If the whole gorge has been cut out since that epoch, at the rate of one foot per year, thirty-five thousand years would be required. It has been, however, more than once suggested that a portion of the gorge is pre-glacial. Prof. Dana supposed about one mile of it to be pre-glacial, but Mr. Belt, after a personal investigation, concludes that the gorge above the whirlpool was excavated nearly up to the present position of the falls in pre-glacial times. After giving the evidences upon which he founds his opinion, he says: "If the conclusion at which I have arrived is correct, that the gorge from the whirlpool to the falls is pre-glacial, and that the present river has only cut through the softer beds between Queenstown and the whirlpool, and above the latter point merely cleared out the pre-glacial gorge in the harder rocks, twenty thousand years or even less is amply sufficient for the work done, and the occurrence of the glacial epoch, as so measured, will be brought within the shorter period that, from other considerations I have argued, has elapsed since it was at its height."

A calculation of a similar kind has been made by Prof. Winchell, upon the recession of the falls of St. Anthony, since the last glacial epoch. These falls, in the Mississippi river, were discovered in 1680, and a continuous record of their recession may be found since then. A narrow gorge, formed by their recession, extends from the falls to Fort Snelling, eight miles south. Below this point the valley widens, and shows evidence of having been excavated in pre-glacial times. From the falls to Fort Snelling, however, the drift, which lies above the rocky walls of the gorge, has been cut through so as to form a bluff on either side; a fact, showing the post-glacial age of this gorge. An ancient channel of the river, now filled with glacial drift, is described and the evidence seems decisive that, since the glacial epoch, the river, having been forced out of its old channel, has cut out a new one eight miles long, through the rock. Unlike the rocks at Niagara, those at the falls of St. Anthony are horizontal and of unvarying composition, and any conclusions made here will be of much greater accuracy. Prof. Winchell gives three separate measurements, which result in the following terms of years required for the total recession, viz.:—12,103 years; 6,276 years; and 8,202 years. He holds that

an average of these rates—8,860 years—represents the time which has elapsed since the maximum cold of the last glacial epoch.

Thus we find, that if any reliance is to be placed upon such calculations, the time of the melting of the glacier need not be longer back than from 10,000 to 15,000 years ago. The conditions at that time will be treated of in our next lecture. It may be that as investigations are carried further, they will result not so much in proving man of very great antiquity, as in showing how much more recent than usually supposed was the final disappearance of the glacier. Here, however, we are entering a field where many sciences meet and where each must help the other.

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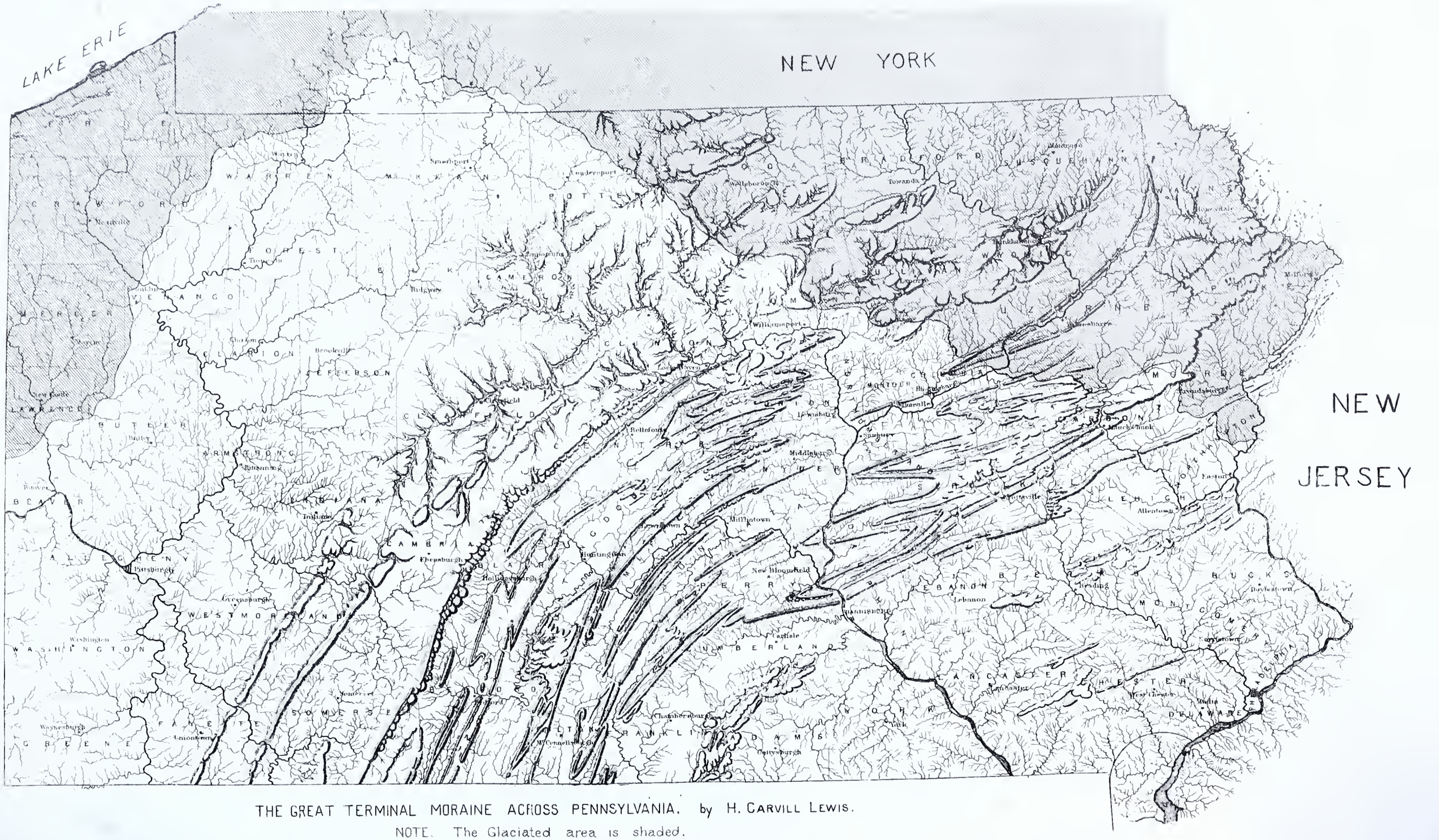

THE GREAT TERMINAL MORAINE ACROSS PENNSYLVANIA. by H. CARVILL LEWIS.

NOTE. The Glaciated area is shaded.